# High Performance Buildings Research and Implementation Center (HiPerBRIC)

A National Laboratories – Industrial Consortium – Academia Partnership

***To help transform the commercial buildings industry in the U.S. and abroad***

A partnership between national labs-industry-academia-building professionals to help

create the science, human capital, and implementation tools needed to enable intelligent and efficient buildings

achieve 90% reduction in energy consumption in new building construction and >50% energy consumption in commercially viable retrofits by 2030

United Technologies

## Overview

It is clear that the United States must transform its economy from one dependent on petroleum and coal that result in high greenhouse gas emissions, to one based on alternative fuels, low-carbon or carbon-free fuels, and one that uses energy much more efficiently [1]. Approximately 20% of the US energy consumption occurs in commercial buildings [2]. New commercial buildings must be substantially more energy efficient than current ones. The U.S. is saddled with a large long-lived stock of energy-inefficient commercial buildings that must be retrofitted to enhance efficiency. These sectors provide tremendous opportunities for significant reduction in energy consumption, provided the science and technology as well as policy tools are developed to address these challenges. Hence, the United States must drive an innovation revolution to develop the scientific and engineering tools required to enable the transformation of the U.S. commercial building sector.

We propose to develop a national research and development center to meet these challenges and to lead the way to an innovation revolution in the design and operation of energy efficient commercial buildings. The proposed **H**igh **P**erformance **B**uildings **R**esearch & **I**mplementation **C**enter (**HiPerBRIC**) will be a partnership between the National Laboratories, Industry and Academia that engages relevant stakeholders to provide the broad and deep R&D base needed to enable market transformation in the commercial building sector. The key purpose of HiPerBRIC is to assemble a unique team of scientists, engineers, architects and economists from industry, national labs, and universities to address the issue of reducing energy consumption in commercial buildings that *no single institution can address individually*. In addition, it will address energy policy, regulations and educational issues to ensure the R&D is transitioned into products and the marketplace.

> ***The vision of HiPerBRIC*** *is to enable the transformation of the U.S. commercial buildings sector in 15-20 years, starting now, by saving greater than 4 Quads of energy, and reducing by 400 million tons of $CO_2$ annually. This will be accomplished by targeting a reduction in energy consumption of 90% in new buildings (over current baselines) and more than 50% in retrofits, at reasonable economic costs, while simultaneously improving health, comfort, safety/security, and water usage, in buildings.*

To achieve this is non-trivial, and constitutes a **technological grand challenge**. To compare the magnitude of this energy saving, note that the current magnitude of electric power generation from coal-fired power plants in the US is about 7 Quads per year.

Clearly, the magnitude of demand reduction proposed by HiPerBRIC could have a very significant impact on energy security and green house gas emissions. We believe that the HiPerBRIC targets are technologically within reach and can be accomplished through innovative R&D efforts conducted by extraordinary multidisciplinary teams (comprising talent from National Labs, Universities, and Corporate Research Centers).

The recent **DOE Building Technologies Program Multi-Year Program Plan** (MYP) [3], calls for research programs that use a whole buildings approach to energy efficiency that takes into account the complex and dynamic interactions between a building and its environment, among a building's energy systems, and between a building and its occupants. ***This "whole buildings" - integrated systems approach is the centerpiece of the HiPerBRIC R&D approach and it will be complemented by an***

***additional focus on technology demonstrations.***

Analysis suggests that this whole building integrated systems approach has already achieved energy savings of 30 percent beyond those obtainable by focusing solely on performance enhancement of individual building components, such as energy-efficient windows, lighting, and water heaters [3]. The integrated systems approach necessary to achieve the non-incremental HiPerBRIC goals must be balanced with component development and optimization driven by system-level requirements. HiPerBRIC R&D and demonstration projects will focus on efforts that enable the development of science and engineering tools required to address innovative technologies for system-level design and operation of buildings.

> ***The HiPerBRIC mission*** *is to develop the enabling science and engineering tools which will be structured in a way to achieve the stated R&D goals, address equipment standards and analysis, technology validation and market introduction. Consequently, HiPerBRIC will require corresponding and coordinated efforts in technology demonstrations, education, outreach, technology commercialization and policy tools. HiPerBRIC will provide a mechanism to coordinate intra- and inter-agency collaboration and other critical drivers of innovation.*

We anticipate the development, testing and validation of many of these technologies to have a 5-10 year time horizon, with key enabling results appearing in the 3-5 year time frame. A multi-year staged approach to accomplishing technology maturation and transition is proposed. A critical element of this staged approach is identification (via workshops) and early investment (via teams and funding) in small scope "seedling projects" and large "focused research projects". These multi-institutional projects will focus HiPerBRIC on filling specific tool and technology gaps that will enable large energy efficiency gains, while providing feasibility and existence proofs via scaled demonstrations of mature technologies.

We feel that HiPerBRIC offers a unique aggressive and economical approach to achieve these goals, which will lead to a resurgence of U.S. technological superiority in engineering products for decades to come, and will enable the transformation of the U.S. commercial buildings sector. The benefits of such a transformation are indisputable. In particular, HiPerBRIC will help:

- Deliver saving to the U.S. economy of more than $100 billion per year at today's energy prices
- Substantially improve America's energy security
- Provide a substantial edge to U.S. corporations in technological competitiveness in the booming building construction in China, India, and other parts of the world
- Reverse the long and steady decline in science and technology enrollment in the U.S. universities by attracting our brightest young minds to meet the challenge
- Lead to a flowering of new innovations and products as spin-offs from a new technology revolution that is necessitated by this project
- Provide an improved environment for our future generations by reducing pollution impacts from reduced electricity demand, and lastly,
- Help "Save the Planet" in terms of substantially reducing greenhouse gas (GHG) emissions from the U.S., and from other parts the world from energy use in buildings

## 1. Vision, Goals, Mission and Value

**The HiPerBRIC vision** is to enable the transformation of the U.S. commercial buildings sector in 15-20 years, starting now, by saving greater than 4 Quads of energy, and reducing by 400 million tons of $CO_2$ annually. To achieve this vision, the **HiPerBRIC goals** are to reduce energy consumption by 90% in new buildings (over current baselines) and by more than 50% in retrofits, at reasonable economic costs, while simultaneously improving health, comfort, safety/security, and water usage, in buildings. Figure 1 shows the magnitude of the energy savings as compared to the electricity generated from various sources in 2006. This is based on a 1.7% per year growth in new commercial floor space in the US. The growth rates in China and India are substantially higher at 7% and 8.5%, respectively, which provide a significant opportunity for the US to create technologies and policies for these developing economies to adopt. Clearly, this magnitude of demand reduction could have a very significant impact on energy security and green house gas emissions.

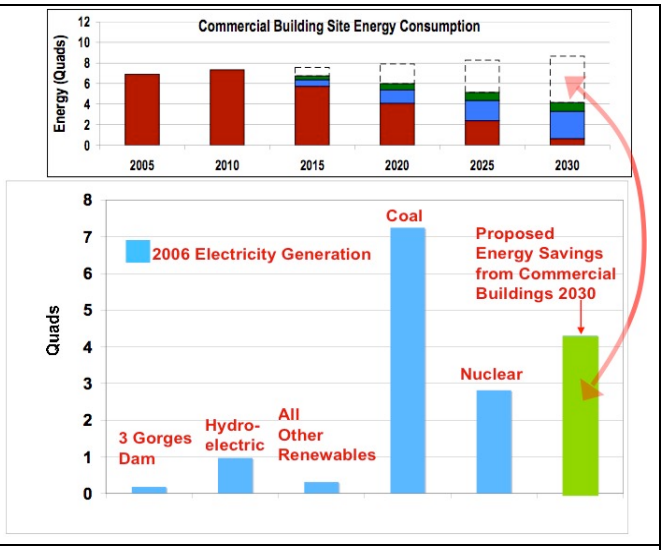


Fig. 1 (Top) Total reduction in energy consumption in commercial buildings if by 2030 one can reduce consumption by 90% in new buildings and 50% in existing ones. (Bottom) Comparison of energy savings in 2030 to electricity generation in 2006 from various sources.

We believe that the goals HiPerBRIC are technologically within reach and can be accomplished through innovative R&D efforts conducted by extraordinary multidisciplinary science and engineering teams (comprising talent from National Labs, Universities, and Corporate Research Centers). HiPerBRIC is envisioned to be a National Lab-Industry-University Partnership to create a global innovation hub in high-performance buildings and attract the world's best scientists, engineers, architects, and social scientists from national lab, academia, industry, and investment community to work on high-performance buildings. HiPerBRIC is a public-private collaboration with participation from:

1. a partnership of national laboratories led by Lawrence Berkeley National Lab (LBNL);
2. a consortium of companies led by United Technologies Corporation (UTC);
3. a group of Universities led by Univ. of California, Berkeley (UCB).

**The HiPerBRIC mission** focuses on the development of comprehensive R&D and demonstration programs that are based on ***an integrated systems approach to whole building research***. These programs will address complex multi-scale whole building dynamics, modeling uncertainty and the interactions between a building, its component systems and disturbances. Although the integrated systems approach is essential in order to achieve the HiPerBRIC goals, it is clear that research in component optimization, component system integration and subsystem optimization will play an important role in achieving these goals. However, HiPerBRIC R&D and demonstration projects will focus on efforts that enable the development of science and engineering tools required to address integrated design and operation of whole buildings.

This approach directly addresses the needs identified in the DOE MultiYear Plan [3], that are articulated as:
*"The challenges inherent in designing and operating high performance buildings and ZEBs [zero energy buildings] demand a number of breakthroughs, both in technology, including software and information technology, and in the fundamental knowledge of optimizing whole building performance through integration and component operation. Systems integration and improved component technology (HVAC, lighting, windows, etc.) are required in order to achieve progressively higher levels of energy performance."*

**The HiPerBRIC mission** is also to develop the enabling science and engineering tools which will be structured in a way to achieve the stated R&D goals, address equipment standards and analysis, technology validation and market introduction. Consequently, HiPerBRIC will require corresponding and coordinated efforts in technology demonstrations, education, outreach, technology commercialization and policy tools. HiPerBRIC will provide a mechanism to coordinate intra- and inter-agency collaboration and other critical drivers of innovation.

In order to achieve the stated goals as envisioned by HiPerBRIC and to fulfill the mission statement above, HiPerBRIC will:

- *Build R&D Teams*: These unique multidisciplinary teams of scientists, engineers, architects, and economists will conduct comprehensive R&D, demonstration, and implementation programs designed to achieve the HiPerBRIC goals. It is expected that a "typical" research team will be composed of scientists and engineers from national labs, academia and industry so that all three viewpoints and specific research strengths are available to attack these complex problems.
- *Create Revolutionary New Science and Technology Tools*: HiPerBRIC will initiate and manage a set of R&D activities that focus on an ***integrated systems approach*** to buildings design and operation, engineering design methodologies, and lead to mature hardware and software tools that are scalable and widely deployable in our current and future building stock. When appropriate, we will draw on buildings research and existing work around the world to develop new components for integration in end-use systems.
- *Conduct Technology Demonstrations and Enable Transition*: Technology demonstrations are an essential component of technology transfer. Also, technology transfer in the buildings sector will require training to implement these technologies and engineering practices by engaging and leveraging the various stakeholders in the buildings industry through demonstration projects, technical education, training, commercialization, and policy support.
- *Develop a Roadmap for Success*: HiPerBRIC will work with the DOE and other stakeholders to create an outcome and milestone roadmap with the goal of achieving the vision in the next 15-20 years.

**The key values** that HiPerBRIC will create for both the National R&D agenda as well as to member institutions will be to:

- foster open development of pre-competitive platform, best practices, testing and validation of results

- enable technologies (hardware and software) and integrated systems that will be identified, evaluated and matured to reduce risks for commercialization;
- create a new generation of scientists and engineers trained in systems approaches to realize energy efficiency in the commercial building stock;
- create job growth through revitalizing the US commercial buildings industry that includes component and systems suppliers, architects, builders, and building operators;
- create a unique *National Building Systems Test Facility* at LBNL that will incorporate both a physical infrastructure and also a virtual presence to evaluate, validate and mature new technologies in real integrated building systems and thereby enable commercialization, education, and training.

Historically, most of the buildings research has emphasized new construction, new building systems, tools and techniques to build an energy efficient building. While this is important and must be pursued, one should also look at existing buildings since the new building floor space is expect to grow at 1.7% per year in USA. HiPerBRIC will address both needs. HiPerBRIC will tackle the complex problem of operating today's buildings to optimal levels of energy efficiency and designing retrofits to make major reductions in the energy use of the existing stock.

## 2. HiPerBRIC RD&D Output & Implementation Effort

HiPerBRIC's combination of RD&D and implementation activities are critical to enable market transformation. These activities will involve collaboration with various stakeholders in the buildings industry that include but are not limited to: Utilities, Other State Agencies, Industry Organizations (e.g., ASHRAE, AIA, SMACNA), Building Construction firms, A& E firms, Building Materials & Equipment Suppliers, Building Owners & Operators, ESCOs, Service Contractors, as well as Community Colleges that will undertake Building Manager Training. The results of this activity will be:

*Technology*

- Identification of gaps in technology and policies based on technical and market assessments (both for retrofits and new buildings).
- Design methodologies and engineering tools for ensuring robust and scalable high performance building design (for new buildings)
- Hardware and software technologies based on an integrated systems approach that can be used for design and operation of both new and retrofitted existing buildings

*Market*

- Creation and licensing of intellectual property.
- Formation of new joint ventures and business models that create jobs to commercialize new technologies and thereby revitalize the buildings industry.
- Provide technical support for codes, standards, incentives, and policies for designing new buildings, and retrofitting, and operating all buildings.
- To serve the global commercial buildings community by providing advice and bridge the emerging RD&D to real-world applications for reducing energy consumption while enhancing the indoor environment.

*National Building Systems Test Facility*

- A facility to help users validate and test the performance of hardware and software in real integrated building environment to reduce risk and enable commercialization

*Demonstration Projects*

- Engage key stakeholders in the buildings industry to achieve "out of scale" impact by enabling first small-scale then large-scale demonstrations that can be scaled up to the entire building stock. The demonstrations will leverage the 3-5 year output of HiPerBRIC technologies.

*Education & Training*

- Liaise with educational institutions and training organizations to define the new knowledge and skills required by the methods, systems, and tools developed in HiPerBRIC including training to trainers for widespread deployment.
- Develop joint education programs at senior undergraduate and graduate levels between architecture and engineering schools for building design and operation.
- Use university buildings and facilities as case studies and demonstration sites for advanced monitoring, control, simulation models, prototypes, component, and systems research.
- Engage & facilitate professional and vocational training with community colleges and other organizations for building design, construction, commissioning, energy analysis, energy accounting, and operations.
- Use of the *National Building Systems Test Facility* for education and training.

## 3. Gaps, Barriers & Opportunities

The gaps in the current approach to reducing energy consumption in buildings can be succinctly depicted (see Fig. 2) in breadth versus depth. Two types of approaches exist, namely:

- Those that use incremental change (commissioning, tune up, retrofit programs) to achieve on an average 10-15% reduction, but can be widely deployed. ESCOs are an example of this approach. The payback period on average is typically about 10 ± 5 years.
- Those that are one-off zero energy buildings that have deep cuts in energy consumption but cannot be widely deployed because of long payback period and/or specificity of the design.

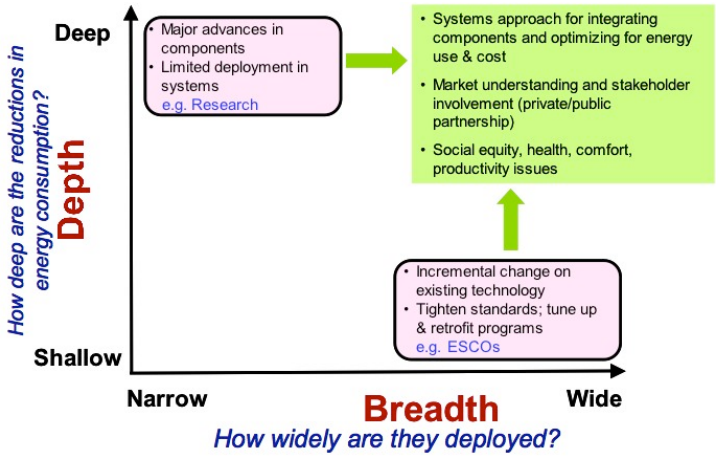


Fig. 2 Gaps in breadth and depth for designing, retrofitting and operating buildings.

***While these approaches are necessary, they are insufficient to result in deep cuts in energy consumption (90% in new buildings, >50% in retrofits) while making it economically viable for quick and wide market adoption.***

Some key barriers are:

*Science*

- Science and engineering foundations of how to design and operate large and complex cyber-physical systems that contain that contains multiple levels of spatial hierarchy, dynamical time scales, and multiple interacting components is either partially developed or missing.
- Interconnected components and sub-systems introduce new types of dynamics and interactions that can reduce the reliability and robustness of building designs and for which no methodologies and tools exist

*Technology*

- Buildings are not widely monitored for energy performance, and hence it is not widely known where the faults and operational problems are, and how a building gets "detuned". Even when necessary instrumentation is in place, data streams are large and complex with no tools or standard practices to provide insight or actionable information.
- A systems approach has not been adopted widely for designing and operating buildings. Component level improvements, while important and necessary, are insufficient and unlikely to produce deep cuts in energy consumption.
- Verification of innovative system concepts for buildings currently must rely on cost-prohibitive full-scale testing and tuning due to lack of robust and scalable design methods/tools

*Market and Economics*

- Market and value chain is fragmented, preventing an integrated approach from design, to deployment, to operation.
- Current payback periods for retrofits are typically 10 ± 5 years preventing wide scale adoption

*Policy and Regulations*

- Current policies are based on designed performance, whereas they ought to be based on measured performance. Measurement standards to support this concept do not exist.

To enable the envisioned market transformation and to address these barriers, HiPerBRIC has, as its goal, creation of comprehensive RD&D and implementation programs.

## 4. Research, Development, and Demonstration Effort

**4.1 Gaps in Science and Engineering:** A commercial building is a large and complex physical system that contains multiple levels of spatial hierarchy, dynamical time scales, and multiple interacting components. When such physical systems are integrated with digital information systems that have their own time scales and hierarchy, additional complexity is generated. The science and engineering foundations of how to design and operate such large and complex cyber-physical systems is either partially developed or missing. This is a non-trivial endeavor that must be approached systematically.

***One of the HiPerBRIC goals is to create the scientific and engineering foundations for designing and operating complex building systems.*** Without these foundations, it is hard to imagine that any technology can be developed into robust, adaptable, and scalable technologies.

**4.2 Technology Vision**: Once these scientific foundations are developed, we envision them to form the bedrock of technologies to design and operate future zero net energy buildings with significant integration of energy, mass and information flows in sub-systems such as HVAC, lighting, plug loads, power delivery, on-site generation, and real-time demand response. For example, we envision future buildings to be operated using a Building Operating Platform (BOP), as depicted in Fig. 3, that captures the interactions and dynamics between subsystems, and optimizes the system-level

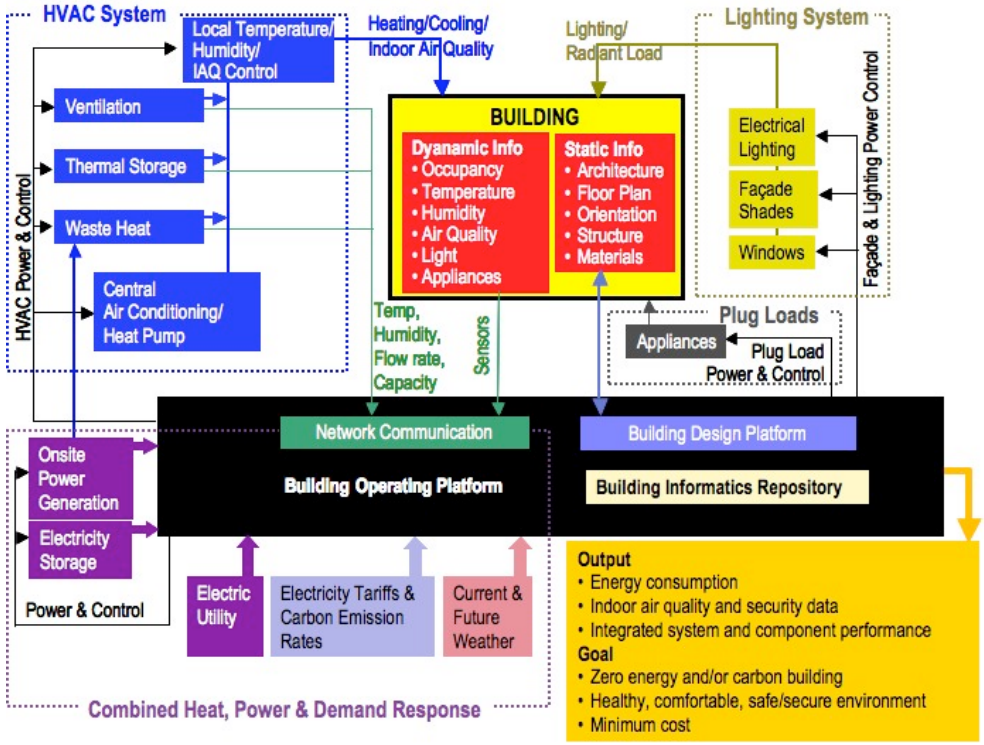


Fig. 3 Schematic of the energy, mass and information flows that must be analyzed and optimized by the building operating platform (BOP) in an integrated systems approach. The BOP would operate the building to optimize comfort, security and health of occupants while minimizing energy consumption, cost, and/or carbon footprint.

performance according the needs of the building occupants and operators. The goal of the BOP is to maximize comfort, health, and security while minimizing the energy consumption, cost, and/or carbon footprint of a building. It needs to be adaptable and robust since it has to be deployed in various types

of building design and environment. For the BOP to function, it needs a building informatics repository, which will also enable a Building Design Platform (BDP) for designing zero net energy building in an integrated manner.

In developing BOP and BDP, HiPerBRIC will

- Leverage techniques and tools that are already developed and integrate them with new approaches
- Make the knowledge and tools available to the whole buildings community
- Develop the technology as an ***open platform*** for the whole buildings community to use worldwide. For example, the standards and protocols must be open so that one could create a plug-and-play environment where subsystems from different vendors could be integrated seamlessly.

**4.3 Building Performance Measurement and Testing Program**. The goal of this program is to evaluate and deploy whole-building, system, and component level solutions that demonstrate energy reduction via experiments in representative building environments (described in Section 4.4). The project goals in the performance measurement and testing program will target energy reduction through the following three areas:

- Monitoring, Control, and Diagnostics: Open-platform sensor communication and information management infrastructure for monitoring and analyzing occupancy, lighting, indoor environment, energy/mass flow and diagnosing system- and component-faults in HVAC, lighting and other delivery systems. Continuous energy monitoring and component, system, and whole-building performance metrics. Common methods for continuous feedback and user interfaces for energy, environmental and economic performance. New methods to improve control in buildings will focus on understanding loads, occupancy and granularity of control to greatly reduce energy waste from heating, cooling, ventilating and lighting spaces that are unoccupied.

- Integration-Enabled Component and System Development: Development of building components (advanced materials) and systems (power delivery, combined heat and power, HVAC, lighting, and other systems) that: (i) push the limits of sub-system performance; (ii) with hardware/software interfaces that allow plug-and-play integration with other components and with the Building Operating Platform (BOP). New equipment components and systems will be developed, evaluated and integrated in test facilities, modeling tools, and related systems to accelerate deployment of cost-effective technologies. New low-energy strategies to be evaluated and integrated include those listed below. However, HiPerBRIC envisages addressing only those development challenges that are currently not addressed anywhere else. On the other hand, evaluation and integration can include a wider range of products and systems. The strategies, broadly defined, are:
  1. Reduce lighting energy:
     a. Efficient sources, e.g. solid state
     b. Improved luminaires and lighting design
     c. Daylighting
        - Improved devices, e.g. light tubes, holographic films

- Improved facades – glazing, shading, and daylighting control
- Building form

2. Reduce HVAC energy
   a. More effective methods of conditioning occupied spaces, e.g. minimize air mixing with stratified systems such as displacement ventilation
   b. Efficient thermal distribution systems, e.g. hydronic systems (water is a much better heat transfer fluid than air)
   c. Cooling: direct dissipation of heat to the ambient wherever and whenever possible, e.g. evaporative cooling, radiation to the night sky; efficient low lift chillers; enhanced dehumidification methods
   d. Passive solar heating
   e. Improved heat reclaim
3. Reduce refrigeration energy, especially in supermarkets and warehouses
   a. Develop refrigeration systems that can integrate with HVAC systems
   b. Improve the performance of display cases, e.g. reduce the need for anti-sweat heaters
4. Reduce miscellaneous and plug loads; liaise with office and other equipment manufacturers, vertical transport, cooking and food service.

- Test and Validation: The goal is to create and use the *National Building Systems Test Facility* at LBNL (described in Sec. 5) and complementary user facilities at other national laboratories, to test and validate the performance of BOP, Building Design Platform, new materials and HVAC systems. The purpose is to fine tune and debug the technologies before rolling them out in real integrated buildings, which have major cost implications if they perform sub-optimally. To ensure robustness under wider range of operating conditions (e.g., weather, user behavior) and scalability to larger-scale buildings (compared to proposed LBNL facility), the test bed experiments will be augmented with modeling and design tool developed under BOP using a "hardware-in-the-loop" approach. Testing and validation will be done through integration of monitoring/diagnostics tools during operation using the BOP along with integration-enabled components.

**4.4 Building Energy Systems Engineering Program**. Buildings are a physical system that contains multiple levels of spatial hierarchy, dynamical time scales, and multiple interacting components. As part of HiPerBRIC we envision them to be integrated with digital information systems that have their own time scales and hierarchy, which creates complexity. If unaddressed, these dynamical interactions and spatial hierarchy poses risk in reducing energy consumption and creating uncontrolled indoor environment. If understood and addressed, they provide an opportunity for significant benefits. The goal of this program will be to develop the scientific foundations of analyzing and designing large complex cyber-physical systems, which will then be used to create the tools for building design and operation.

We will develop tools and processes that enhance or create new interfaces between subsystems that can significantly enhance system-level performance of buildings for energy efficiency through exploitation of system-level dynamic interactions and system-level design methodologies. A set of simulation tools will be developed to allow seamless interoperability of building data between tools. Each of the tools provides unique interfaces and capabilities to facilitate design and operations analysis. Initial plans for the simulation-based project themes include:

- Building Informatics Repository: Given a building's functional requirements, design constraints and its environment, the goal is to enable system-level design, analysis and synthesis leading to scalable and robust architectures and reduced time-to-market for robust high-performance buildings. Specifically, the tools to be developed will focus on understanding, predicting, estimating and visualizing energy, momentum and information flows in buildings. We will leverage the building energy analysis capability of EnergyPlus, integrated with Building Information Models (BIM) such as the Industry Foundation Classes (IFCs) and modern modeling and simulation techniques for heterogeneous dynamic systems, such as networked embedded systems with multi-scale dynamics. This will create a platform aimed at innovative companies and researchers in industrial and public institutions to identify: (i) optimized approaches to reduce energy consumption through component and system-level modifications; (ii) locations and types of sensors and actuators for monitoring, diagnosing and self-tuning controls of buildings; (iii) economics and environmental impacts of these approaches and their respective cost-benefit metrics.

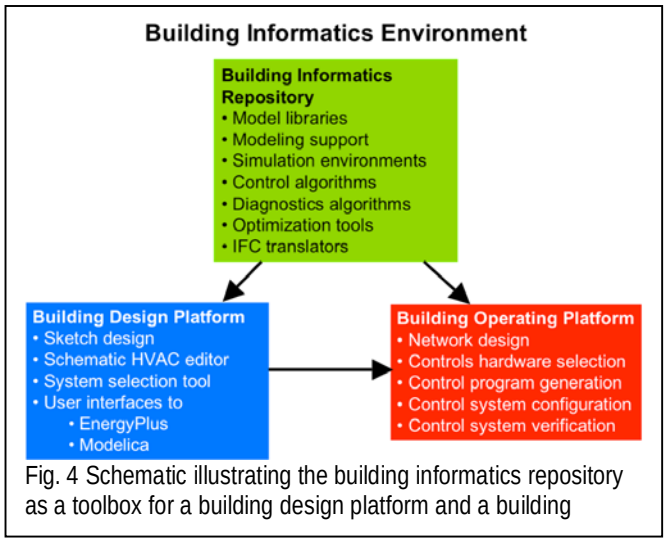

Fig. 4 Schematic illustrating the building informatics repository as a toolbox for a building design platform and a building

  - Audience for Tool - innovative companies, advanced engineers, researchers

- Building Operating Platform (BOP): An open-platform intelligent "building operating system" that: (i) deploys control algorithms developed in BEAM to the Building Automation System for estimation and control of multi-scale dynamic phenomena and energy optimization in buildings; (ii) analyzes monitoring and diagnostics data (sensor data input) in real time; (iii) uses sensor data in conjunction with BEAM in real time for energy analysis and feedback control systems; (iv) exploits interfaces between sub-systems in real-time to minimize energy consumption, peak power, carbon footprint, and cost. The tools and algorithms to be developed include dynamic, physics-based, reduced-order models that are suitable for real-time implementation, and associated hierarchical, feedback control algorithms.
  - Audience for Tool - facility managers, energy service providers, building owners and operators, and researchers

- Building Design Platform: A user-friendly tool for A&E firms to design new buildings and plan retrofits for existing buildings. The Building Advisor will link to product libraries for HVAC components and building materials through Building Information Models. It will contain expert systems for component selection and Building Informatics Repository for energy system modeling. Such a tool will embed all the necessary system-level engineering to identify components and system integration strategies to reduce energy consumption, but would not require users to understand details of the underlying engineering and analysis methods.
  - Audience for Tool - architects, students, business managers, building owners

RD&D will be divided into two categories. The initial development, testing and validation of these technologies will have a 3-5 year time horizon. Aligned with the roadmap will be a multi-year staged approach (see Fig. 5) to accomplishing this technology maturation and transition (denoted by increasing levels of technology readiness level TRL). A critical element of this staged approach is identification (via National Lab-Industry-University workshops) and early investment (via teams and funding) in so called "seedlings" and "focused research projects". These will focus HiPerBRIC in the short term (1-2 years) on filling specific tool and technology gaps and providing feasibility and existence proofs via scaled demonstrations. Specific elements of the tools and technologies to be developed and matured are described in the subsequent sections.

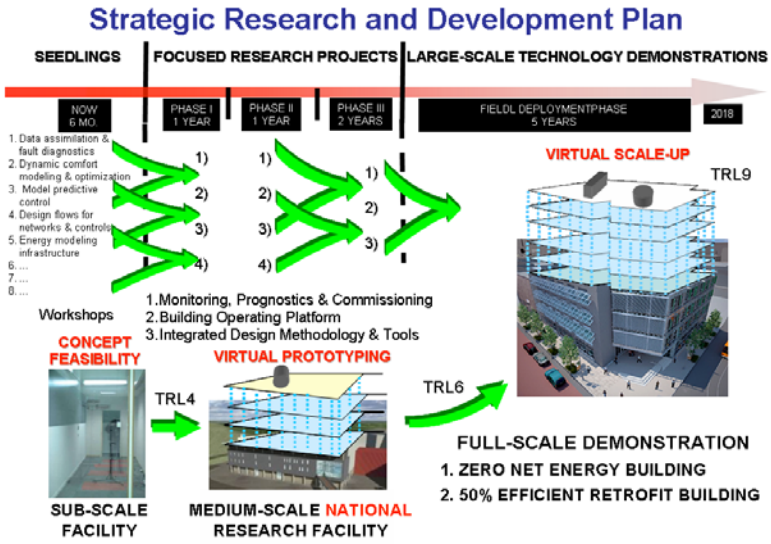

Fig. 5 Proposed multi-year RD&D program to realize HiPerBRIC vision.

## 5. National Building Systems Test Facility

The *National Building Systems Test Facility* will have both a physical structure and virtual presence. The physical structure will contain three types of space:

- *Full-Scale Testing Space* that provides framework of a reconfigurable building where hardware (building materials, sensors, HVAC etc) and software (the Building Operating Platform) can be added and tested and tuned for energy consumption and indoor environment as an integrated system.
- *Collaborative Space* for teams of scientists, engineers, architects, economists, for concurrent engineering design, optimization and analysis.
- *Component Testing Space* to enable hardware development and testing (e.g. coatings for windows, sensor modules) and testing;

## References

[1] P. Ogden, J. Podesta, and J. Deutch, "A new strategy to spur energy innovation," *Issues in Science and Technology, National Academies*, vol. Winter, 2008.

[2] ""Who Plays and Who Decides: The Structure and Operation of the Commercial Building Market", ," A Report Prepared for the U. S. Department of Energy Office of Building Technology, State and Community Programs,.

[3] "Commercial Integration Approach/Strategies for Overcoming Challenges and Barriers," DOE EERE Building Technologies Multi Year Plan – draft 04/08